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16T/S CTS DESIGN EVALUATION

D. W. Hill, Jr.
ARO, Inc.

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- L. C. Abel who developed the moving Full-Span Concept
- J. P. Newton who performed the Structural Analysis on the Double-Sway and Moving Full-Span Concepts
- R. H. Jackson who performed the Structural Analysis on the Existing Sway Strut
- R. G. Butler who assisted in the preparation of the controls and instrumentation cost and procurement estimate
- D. W. Whitfield and T. L. Donegan who performed the aerodynamic interference calculations for the CTS angular drive head and support struts

SUMMARY

A design evaluation was made of the previously proposed captive trajectory support (CTS) concept utilizing an existing cantilivered sway-strut mechanism. The evaluation showed that the existing strut was structurally inadequate to handle the aerodynamic and gravitational loads.

A full-span, moving-strut concept was examined and proved adequate to meet the requirements of model position accuracy and motion. If procurement is started in FY81, the CTS could possibly be operational in late FY82.

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NOMENCLATURE

de	CTS diameter equivalent of a circle, ft
ℓ	Longitudinal distance from apex of cone, in. (See Fig. 10)
M	Free-stream Mach number
ΔM	Variation in local Mach number from the free-stream Mach number
P_t	Total pressure, psfa
q_∞	Free-stream dynamic pressure, psf
r_1, r_2	Length of lower and upper sway strut, respectively, ft (see Fig. 16)
TS	Axial station, ft
T_t	Total temperature, °F
X,Y,Z	Positions of the CTS pitch center with respect to its midpoint of travel, in the positive axial, horizontal, and vertical directions, respectively, in. (see Fig. 18)
$\Delta X, \Delta Y, \Delta Z$	Deflections at the CTS pitch center in the positive X, Y, and Z directions, respectively, in.
ν, η, ω	CTS pitch, yaw and roll angle, deg
ϕ_1, ϕ_2	Roll angles of the lower and upper sway strut, respectively, deg (see Fig. 16)

1.0 INTRODUCTION

During FY79, feasibility studies (Ref. 1) of several captive trajectory support (CTS) concepts for the AEDC Propulsion Wind Tunnels 16T and 16S were conducted. These concepts were compared with a scaled-up 4T CTS primarily from a comparative cost analysis standpoint. Therefore, design evaluation of each concept was minimal. The final suggested concept was a CTS system in which the horizontal and vertical motions were obtained by angular motions (Double-Sway strut) and the rectilinear axial motion was obtained with a telescopic boom. A multiple roll motion concept was suggested to provide the model pitch, yaw and roll angular motions, with a scaled-up 4T CTS rotational drive head as an alternate.

In the FY80 effort, a design evaluation was conducted to determine if the concept met the test requirements such as positioning accuracy for grid and trajectory simulation and, in addition, a recent high angle-of-attack requirement. The requirements are presented in the Appendix. The design evaluation of the CTS concept consisted of re-evaluating the store and aircraft model loads, model positioning accuracy, and kinematics. The Double-Sway CTS concept was then compared with another proposed concept to illustrate the relative merits of each system.

The work reported herein was conducted at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the Directorate of Facility Maintenance, Repair and Modernization (DEM). The project monitor was Mr. R. Roepke. The study was conducted by ARO, Inc., AEDC Group (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO project number P91T-45.

2.0 APPARATUS

2.1 TEST FACILITY

The AEDC Propulsion Wind Tunnel consists of two closed circuit wind tunnels, 16T and 16S. Tunnel 16T is a variable density, continuous-flow tunnel capable of being operated at Mach numbers from 0.2 to 1.6 and at stagnation pressures from 400 to 4000 psfa. Tunnel 16S is a variable density, continuous flow tunnel that can be currently operated at Mach numbers from 1.5 to 2.4 and at stagnation pressures from 200 to 1600 psfa. The maximum stagnation pressure attainable in either Tunnel 16T or 16S is a function of Mach number and available electrical power.

The test condition requirements for CTS testing in the wind tunnels are a Mach number range from 0.4 to 3.0 with the maximum stagnation pressure and dynamic pressure being 1200

psfa and 500 psf, respectively. The test envelope for 16T/S is shown in Fig. 1. The maximum dynamic pressure of 500 psf will be used in the design evaluation. In reality, the dynamic pressure could be larger depending on the test requirement. The Mach number range was selected based on the test requirements for the most advanced aircraft, whether it be flow-field survey or trajectory testing and the history of such testing in PWT-4T.

2.2 FACILITY TEST SECTIONS

There are two test sections available in 16T for use in CTS testing; the Propulsion Test Section 1 (Fig. 2) and the Aerodynamic Test Section 2 (Fig. 3). It was stated in Ref. 1 that Cart No. 2 was utilized 71% of the time in 16T and is used exclusively for aerodynamic tests (cart configured with full span strut and bulge region). Therefore, test section 1 could be utilized for CTS testing. In the event that the proposed High Angle Automated Sting (HAAS) support system is installed in Test Section 1, the full-span strut sting support system would be removed from the current test section to permit use for CTS testing. The bulge region could possible be utilized for the alleviation of the blockage of the CTS strut. However, two of three available half carts (Fig. 4) are used in 16S to provide a model test section (each cart is 20 ft long). Historical data have shown that from the period of FY70 to FY80 the 16S wind tunnel has been utilized 28%. Therefore, one of the 16S carts (carts 3, 4, or 5) might be considered for CTS testing in both 16T and 16S. This would require having interchangeable wall liners (porous and solid) in the test carts and the frequency of CTS installation and/or removal would be at a minimum.

2.3 AIRCRAFT MODEL SUPPORT SYSTEM

To achieve minimum interference between the CTS and the aircraft model support, it is recommended that the aircraft model be strut mounted and attached to the pitch table support system. The pitch table can be mounted with the centerline of the table in any of the following axial positions downstream of the leading edge of the test sections (Sta. 0): 10 or 20 ft in test section 4; 6.38, 20, or 34 ft in test section 1. The center of rotation of the pitch table should be close to the aircraft model to reduce movement of the aircraft model with changes in angle of attack. This report considers the design evaluation of the aircraft model support system only to the extent of defining the criteria and the impact on CTS design as a result of the high angle-of-attack requirement (physical interference). The aircraft model support system should be as normally provided on a test by test requirement basis.

3.0 MODEL SUPPORT AND CTS CRITERIA

3.1 AIRCRAFT MODEL SUPPORT CRITERIA

The aircraft considered were chosen based on the assumption that most users would want to use available models to

Aircraft	Scale (%)
F-4	5, 7.5
F-14	4.5
F-15	5, 10
F-16	5, 6.7, 9, 25
F-18	6
F-111	4.2, 8.3
B-52	4.9
B-1	3, 6
C-5A	5

reduce the cost of the wind tunnel test program. The available larger sizes as shown in the table above would be adequate to accurately represent the geometric details of the aircraft.

The F-15 is the largest of the tactical aircraft and the C-5 and B-1 are the largest of the transport and bomber classes, respectively. The aircraft lift and drag loads were computed for various geometric scales of these aircraft and are presented in Fig. 5. The 10-percent-scale F-15 model at an angle of attack of 45 deg was chosen for the design envelope. It can be seen from Figure 5 that the C-5 (5%) and B-1 (6%) aircraft loads are within this design envelope. The overall dimensions of a 10-percent-scale F-15 aircraft model are presented in Figure 6. A 20-percent-scale F-15 aircraft model produces loads within the structural limitations of the pitch table (Ref. 1) by which it would be supported. The aircraft aerodynamic loads for an F-15 model of an angle of attack of 45 deg (q = 500 lb/ft^2) and a scale factor of 20% are the following:

Lift Force	25,000 lb
Side Force*	10,000 lb
Drag Force	20,000 lb
Rolling Moment*	16,000 ft-lb

* Flow break-down load (M = 2.0)

In summary, the aircraft support system can be mounted to the existing pitch table without any structural modifications. The solid blockage in the tunnel for the C-5A and F-15 aircraft at various geometric scale factors is presented in Fig. 7. It can be seen that for a 5 percent C-5A or a 20 percent F-15 the solid blockage is less than 1 percent and is considered acceptable. The aircraft model angle of attack is assumed to be zero in calculating these blockage ratios.

3.2 STORE MODEL LOADS CRITERIA

The store model loads for different types of stores at various geometric scales are presented in Fig. 8. The store model loads criteria, which produce the maximum CTS design load, were determined for a 10 percent GBU-15 (CWW). The overall dimensions of a 10 percent GBU-15 CWW are presented in Fig. 9. Since there are a few models that produce greater loads, the wind tunnel dynamic pressure could be lowered to accommodate the testing of those models. The CTS design load criteria are the following:

Normal Force	250 lbs
Side Force	250 lbs
Axial Force	50 lbs
Rolling Moment	4 ft-lbs

The 20-percent-scale air to air missile produces the same normal and side force loads as the 10-percent-scale GBU-15 model. Thus, the air to air missile could be tested with 20-percent-scale advanced tactical aircraft models at high angles of attack.

3.3 CTS MOTION LIMITS CRITERIA

The CTS rectilinear motion limits criteria (Appendix) were determined by a 4-to-1 scale-up of the Tunnel 4T travel limits. These travel limits would produce enough travel for aircraft flow-field surveys in the far field, and also provide enough survey and trajectory motion at the higher aircraft angles of attack. The pitch and yaw range of ±45 deg is sufficient in most cases to satisfy the higher angle-of-attack requirements. In situations where higher CTS pitch and yaw motions are needed, stings with pre-bend angles would be selected to satisfy the motion and minimize the physical interference of the CTS with the aircraft model and/or its support structure.

The CTS linear and angular velocities were selected to require the minimum amount of time to produce a typical trajectory or grid survey. In addition, the linear and angular velocities were chosen to produce a smooth motion along the trajectory path (coordinated motion) and to provide equivalent trajectory generation times for a 10-percent-scale model as for a 5 percent model in Tunnel 4T. The travel and velocity limits and model position accuracy limits required are presented in the Appendix.

3.4 CTS AERODYNAMIC INTERFERENCE CRITERIA

The CTS angular support head for obtaining pitch, yaw and roll motions of the store model can produce, due to its size, aerodynamic interference on the sting supported store model if sufficient distance is not maintained between the head and the store model. Data have been obtained with the Tunnel 4T CTS to determine the aerodynamic interference. The experimental data obtained, and values calculated from a computer code by the PWT Computational Fluid Dynamics Section, are presented in Fig. 10. Data are presented as the effect of the CTS head and the horizontal plate on the freestream Mach No. The calculation for the CTS head was made assuming the head was cylindrical and the head front was a 30° cone. The experimental values show good agreement with the computed values.

The data indicate that the aerodynamic interference effect is minimized at distances greater than about 22 inches. The non-dimensional length-to-diameter (diameter of equivalent circle) ratio for this minimum aerodynamic interference is approximately 3.5. Calculated length, ℓ, for various CTS head diameters are presented in Fig. 11. Also presented is the corresponding calculated solid blockage of the CTS head in Tunnel 16T. For a typical head diameter of 1.0 ft, the solid blockage is less than that of most aircraft models tested in 16T.

3.5 CTS CONTROL CRITERIA

A proposed control system for the CTS operation is shown in Fig. 12. It would be a computer-based, stand alone system that will accept velocity or position commands from either manual controls or a microprocessor-based controller for each degree of freedom. The DMACS minicomputer would acquire the wind tunnel test condition data and the DDAS would acquire the store model force and moment data and 6-CTS positions. The velocities or positions would be determined by the trajectory generation computer. The continuous motion technique via velocity control is currently being implemented in Tunnel 4T to greatly increase the data productivity. Also shown in Fig. 12 is a proposed interim computing network that would provide the move-pause motion, or position control technique.

4.0 DESIGN EVALUATION OF CTS CONCEPTS

4.1 GENERAL

The proposed Double Sway strut CTS design with the double roll mechanism, as proposed in Ref. 1, was evaluated to determine if kinematics and model position control accuracy,

including structural integrity, could be met. The double-sway concept was then compared with another proposed concept (Ref. 4) to illustrate the disadvantages of the double-sway concept. Also presented is a comparison of the double roll and the proposed harmonic drive head concept.

4.2 DOUBLE-ROLL DRIVE HEAD CONCEPT

The proposed double-roll rotational drive head was proposed in Ref. 1 as the selection over a scaled-up 4T CTS drive candidate. The original design of the Tunnel 4T CTS incorporated store model support stings were straight, long, and offset to the drive head. Because the stings were straight, when the store experienced pitch or yaw angular movements the sting would frequently collide with the aircraft model or its support sting. New store model sting supports were designed to minimize the occurrence of physical interference. The stings were shortened so trajectories could be obtained with minimum physical interference. An illustration of the physical interference of the double-roll mechanism head with an aircraft fuselage during a trajectory is shown in Fig. 13. Also shown for comparison is the proposed harmonic drive head concept. Not only is there interference of the double-roll mechanism with the aircraft fuselage during the trajectory, but it would be difficult to position the store in its initial launch position. Limited trajectories would be obtained from the wings of an aircraft due to physical interference of the roll mechanism with the wing. There would not be any advantage to use offset stings to minimize interference in the double-roll mechanism because angular motions would be significantly limited. Since significant manual operation times are required of the system, it would be very difficult for one to determine the necessary gyrations required to position the store model unless a computer is utilized. Therefore, the harmonic drive head is the better of the two concepts presented in Ref. 1. It would be expected that the harmonic drive cost would not be any greater than the double roll drive mechanism.

4.3 HARMONIC DRIVE HEAD CONCEPT

The kinematics of the harmonic drive head presented in Ref. 1 are the same as for the 4T except the pitch-yaw axes are reversed to provide a desired yaw-pitch sequence. The drive head would use a harmonic drive gear to minimize gear wear. Therefore, this type of drive is considered in detail for the design evaluation since it doesn't add to the cost. The harmonic drive head and the double-roll mechanism are shown installed on the Double-Sway Strut in Fig. 14. Although not presented in Ref. 1, an offset sting is shown for the

harmonic head concept. This arrangement is needed to minimize the physical interference.

4.4 DOUBLE-SWAY STRUT CONCEPT

The Double-Sway CTS Concept is shown in Figs. 14 (side-view) and 15 (end view) to illustrate the angular and linear motions. The axial motion, X, is to be obtained by a telescopic boom on which the harmonic drive head is mounted. The telescopic boom would be strut mounted to an existing sway strut and base that was used in a previous 16S wind tunnel test. A pitot probe and sampling probe were mounted to this sway strut and moved laterally in and out of an engine exhaust by an hydraulically actuated control rod.

The Double-Sway Strut Concept was chosen mainly because of the availability of the sway strut, thus hopefully providing a significant cost saving. As pointed out in Ref. 1, there was no structural analysis performed.

The end view of the Double-Sway Strut, showing the roll orientation of the harmonic drive head as proposed, is shown in Fig. 16. Due to the pitch axis not remaining in the same plane for any orientation of the Double-Sway Strut, an additional roll axis would be needed behind the harmonic drive head on the telescopic boom to maintain the drive head in a non-rolling attitude, as shown in Fig. 16. The maximum angle of the existing sway strut is 33 deg, as shown in Fig. 16 with the lower and upper sway strut roll angle notations. In order to traverse as much as possible of the 10 ft by 10 ft. CTS motion envelope, as defined in the criteria, a 9.2 ft long lower strut and a 5.0 ft long upper strut would be needed. An illustration of the resultant CTS motion envelope is shown in Fig. 17. The 9.8 ft by 10 ft envelope is sufficient, although the envelope is offset vertically from the test section centerline.

The existing sway strut was analyzed to determine if the strut, actuator rods, and support base were structurally adequate to withstand the gravitational and aerodynamic loads. Analysis indicated the entire existing strut and base was structurally inadequate for both the starting aerodynamic loads in 16S and the steady loads in 16T and 16S. This is not surprising, since the existing sway strut was designed for a different purpose. The sway strut would have to be redesigned and fabricated, which would result in a significant cost increase over that previously estimated. Additional analyses were made on the Double-Sway strut to determine structural rigidity and thus, model position accuracy. The analysis was compared to analysis of a full-span strut. In the analyses, both the chord length of the strut and telescopic length were held constant. The aerodynamic loads on the telescopic boom were

also held constant. The struts were assumed to be fixed at the ends for the purpose of analysis simplification. The linear deflections at the head pitch center due to the steady state aerodynamic loads and gravitational loads are presented in Table 2 for various strut thicknesses. The linear deflections in the double-sway strut due to the aerodynamic and gravitational loads are significantly larger than the deflections on the full-span strut. The full span has more torsional stiffness than the double-sway strut. The calculated linear deflections decrease as the strut thickness is increased. A 4 in. full-span strut produces 2 percent solid blockage compared to 1.8 percent for the double-sway strut. The linear deflections are dependent on the orientation of the upper and lower struts. The deflections and model positional accuracy for two orientations of the double sway strut are presented in Table 2. Although undesirable, the gravitational deflections can be compensated by the control system, whereas, the linear deflections due to aerodynamic loads would be extremely difficult to compensate by the control system. The positional control accuracy for the double sway strut is assumed to be ±0.10 deg at each rotational joint. The calculated linear deflections at the pitch center due to the angular positional control accuracy are presented in Table 2. Any cantilevered support structure, such as the double sway concept and scaled-up 4T concept, would be structurally inadequate to meet the model positional criteria. From a safety viewpoint, possible collisions could occur between the telescopic boom and wall due to long double sway struts. Also, the double sway could produce more solid blockage, due to standing shock waves or the wake, when the upper and lower sway struts are in a nearly folded position (channel type configuration).

4.5 MOVABLE FULL SPAN STRUT

The analysis indicated the full-span strut would be the best concept for support of the telescopic boom. Several concepts were then analysed and the Movable Full-Span strut was found to be the best choice to provide the required Y-Z motion and model position accuracy. The Movable Full-Span concept is shown in Fig. 18. The telescopic boom is mounted to the full-span strut and is moved vertically along the boom for Z motion and the strut is moved laterally on tracks for the Y motion. The CTS is shown in Fig. 18 with the center of travel at TS=20. For the 16S installation, the CTS pitch center is expected to be TS=10. The Movable Full-Span concept results in a design that reduces the chance of collision between the telescopic boom and tunnel wall, provides better model positional accuracy, and provides the simplest kinematics and operation. There is no appreciable cost difference in the double-sway strut and full-span strut concepts. The requirement for the high aircraft angle of attack doesn't significantly affect the design concept or cost of the system. A more detailed structural analysis of the system is presented in Ref. 4.

5.0 CTS PROCUREMENT

5.1 16T/S CTS PRELIMINARY COST

The preliminary cost estimates for the moving full-span CTS system are as follows

	Design & Other Engineering M-Hrs	Installation & Checkout M-Hrs	M-HR Cost $	Material & Travel Cost $
FY 81	12,560	---	225,000	1,000
FY 82	9,440	8,000	321,000	1,110,000
FY 83	4,300	---	83,000	---
Total	26,300	8,000	629,000	1,111,000

The cost estimates have been adjusted for escalation and fringe for that year. The cost estimates include $76,000 for the trajectory generation computer (ADPE equipment).

5.2 16T/S PROCUREMENT SCHEDULE

There are three basic 16T/S procurement schedules which are presented in Table 3; a basic schedule to provide the full velocity control capability in three years (Table 3a), an accelerated schedule to achieve this in two years by providing immediate procurement authority (Table 3b), and a two-phase schedule which would provide interim position control capability in two years with follow-on conversion to velocity control (Table 3c). The velocity control technique as mentioned in Section 3.5, is used to increase the data productivity. However, with the long lead times needed for the computer procurement, the position interim capability schedule shown is considered to be the most practical from an accelerated schedule point of view. In any case, the design of the CTS system should begin in FY81. Some material procurement would have to begin in FY81 to meet an FY82 completion date.

6.0 CONCLUSIONS

The following conclusions have resulted from a design evaluation of the 16T/S Captive Trajectory Support System:

1. The existing sway strut and base on which the proposed Double-Sway CTS was to be attached are structurally inadequate and would require further design and fabrication, significantly increasing the cost of that CTS system.

2. The harmonic drive head mechanism with the Double-Sway CTS concept is feasible, but another roll mechanism would be needed to maintain a non-rotating pitch-yaw axis.

3. The proposed double-roll drive head mechanism was not feasible because of the angular limitation and resulting physical interference with the aircraft model.

4. The full-span strut is structurally stiffer than the proposed cantilevered double-sway strut.

5. The full-span movable strut concept meets the requirements of model position accuracy and motion.

6. The high aircraft angle of attack requirement doesn't affect the CTS design or cost.

7. The estimated cost of the CTS system is $1,740,000.

8. The CTS system can be operational in early FY83 in the position control mode and in FY84 in the velocity control mode provided some material procurement authority is achieved in FY81.

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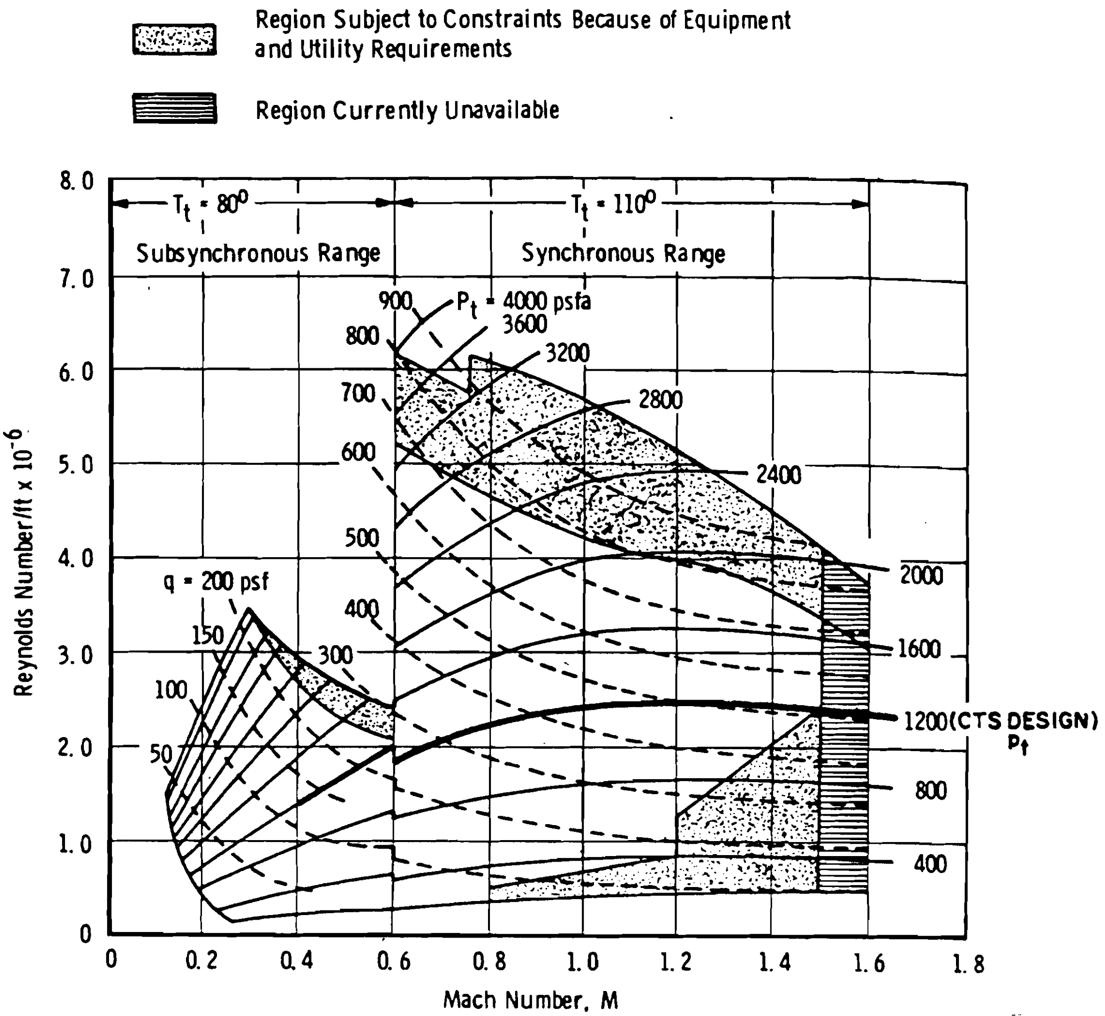
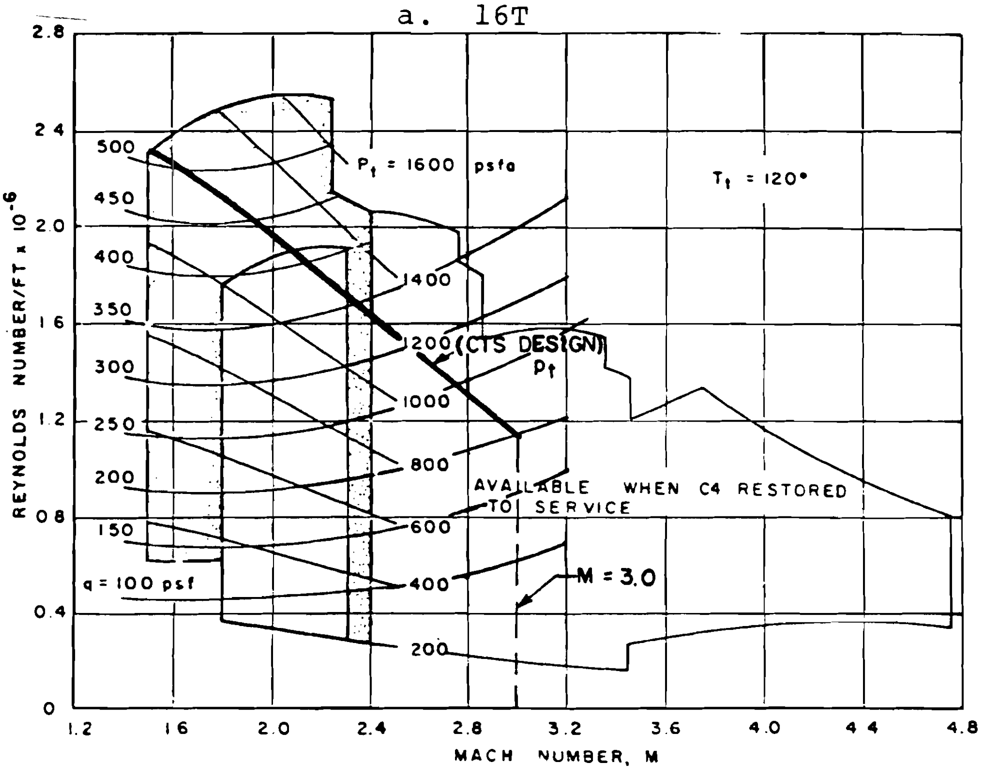


a. 16T



b. 16S

Figure 1. Performance Envelopes for 16T and 16S Showing CTS Design Conditions

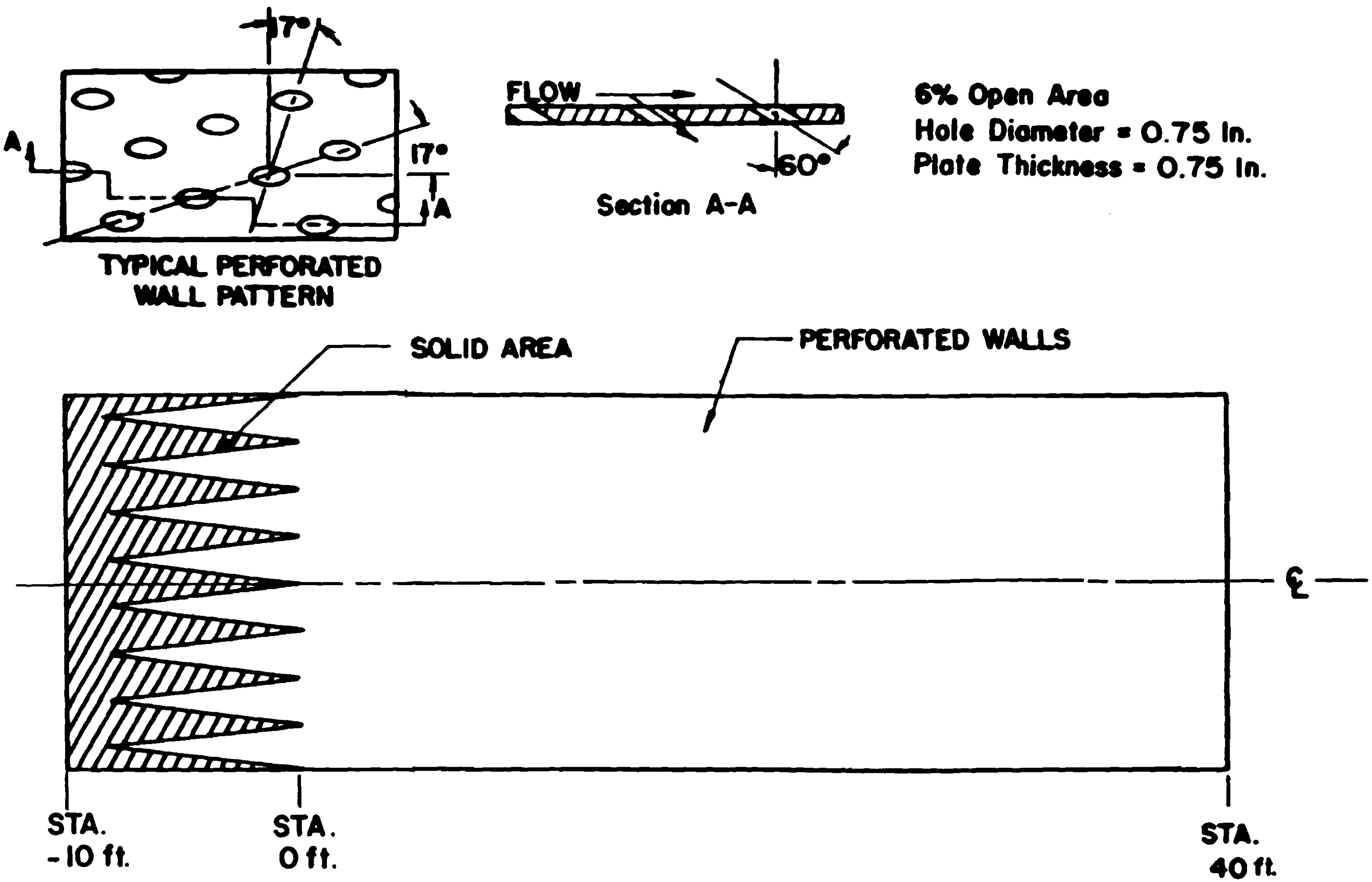


Figure 2. 16T Propulsion Test Section (Cart 1)

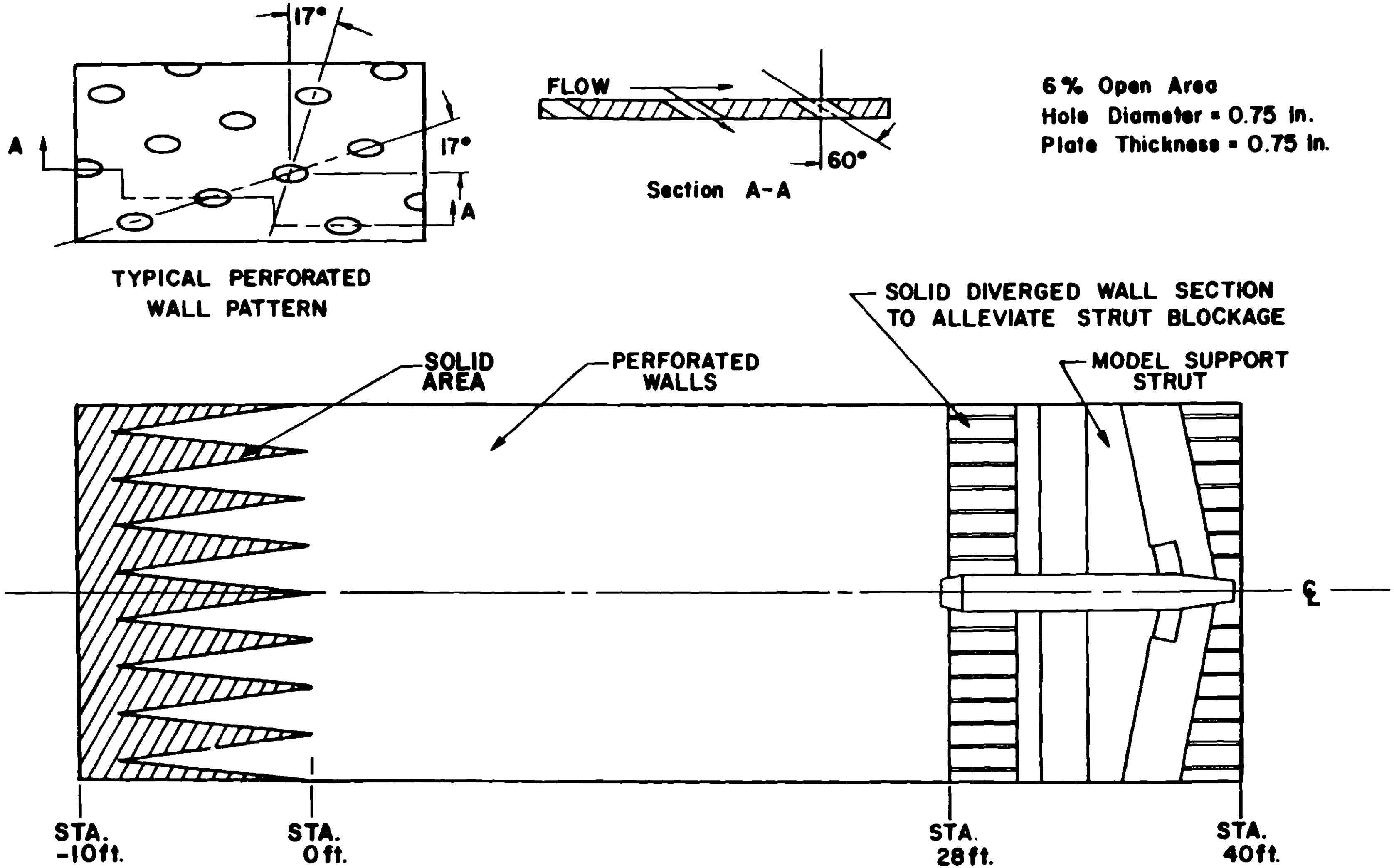


Figure 3. 16T Aerodynamic Test Section (Cart 2)

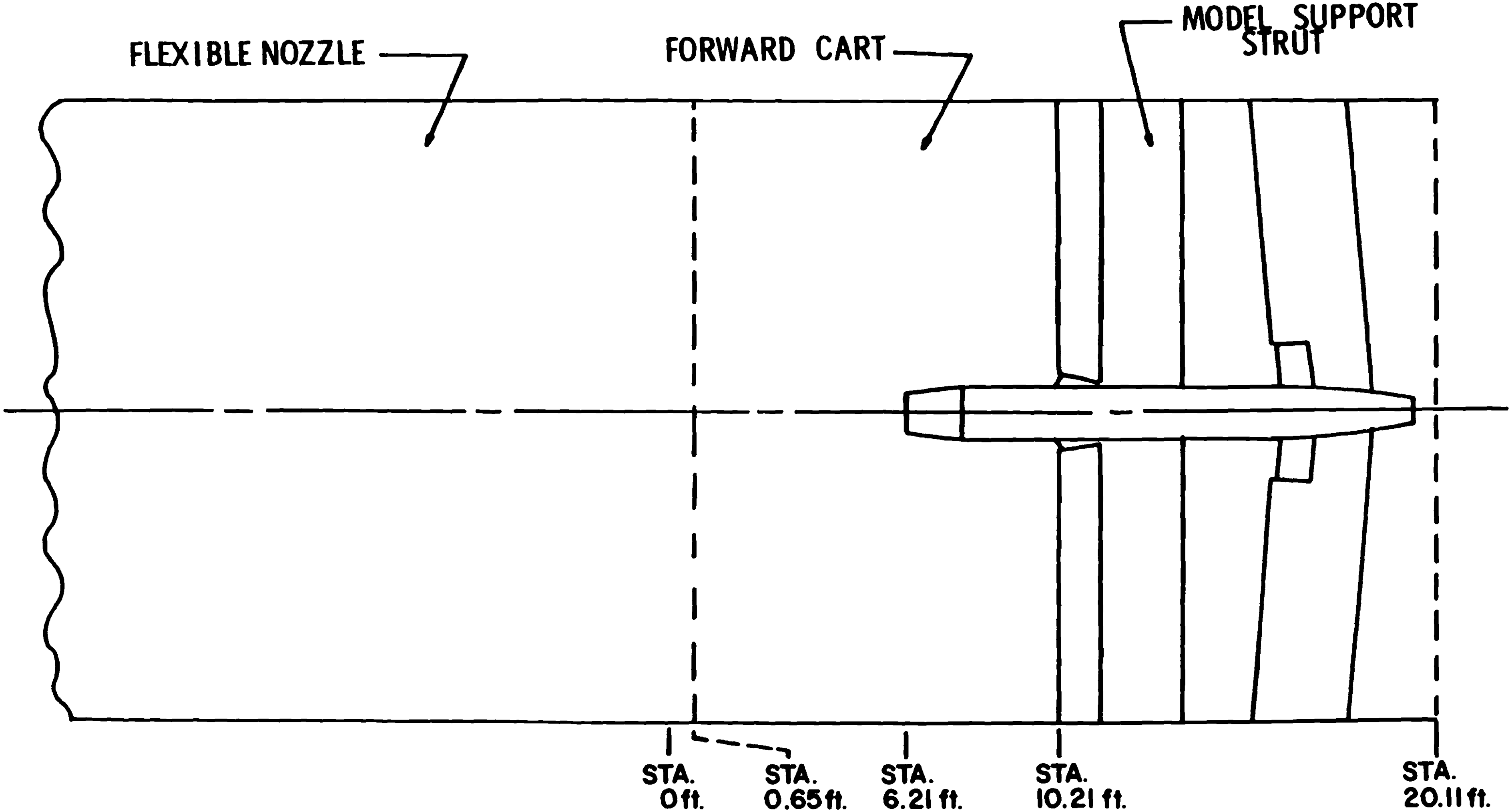


Figure 4. 16S Test Section (Cart 3)

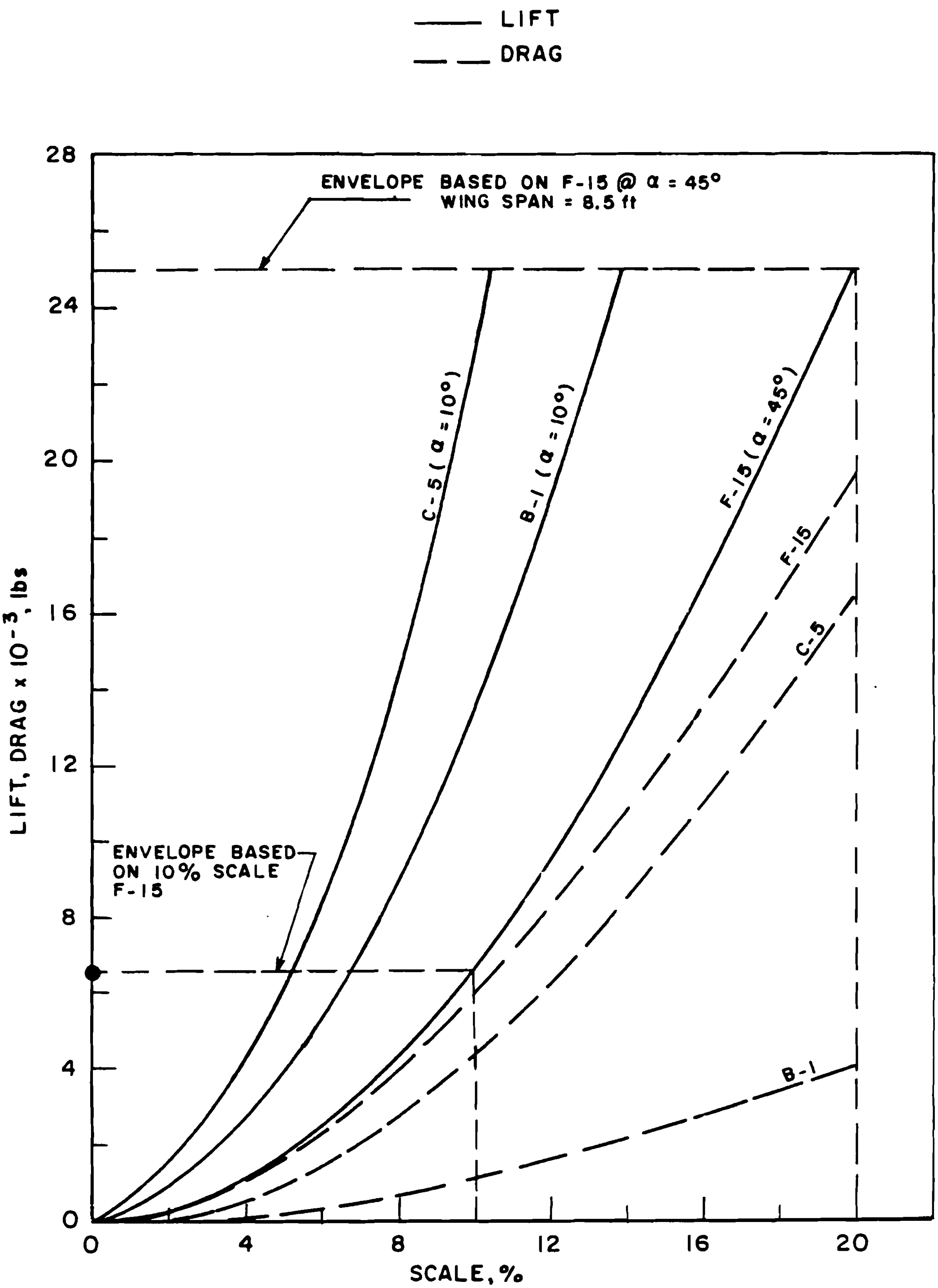


Figure 5. Design Loads at Various Geometric Scale Factors, $q = 500\ lb/ft^2$

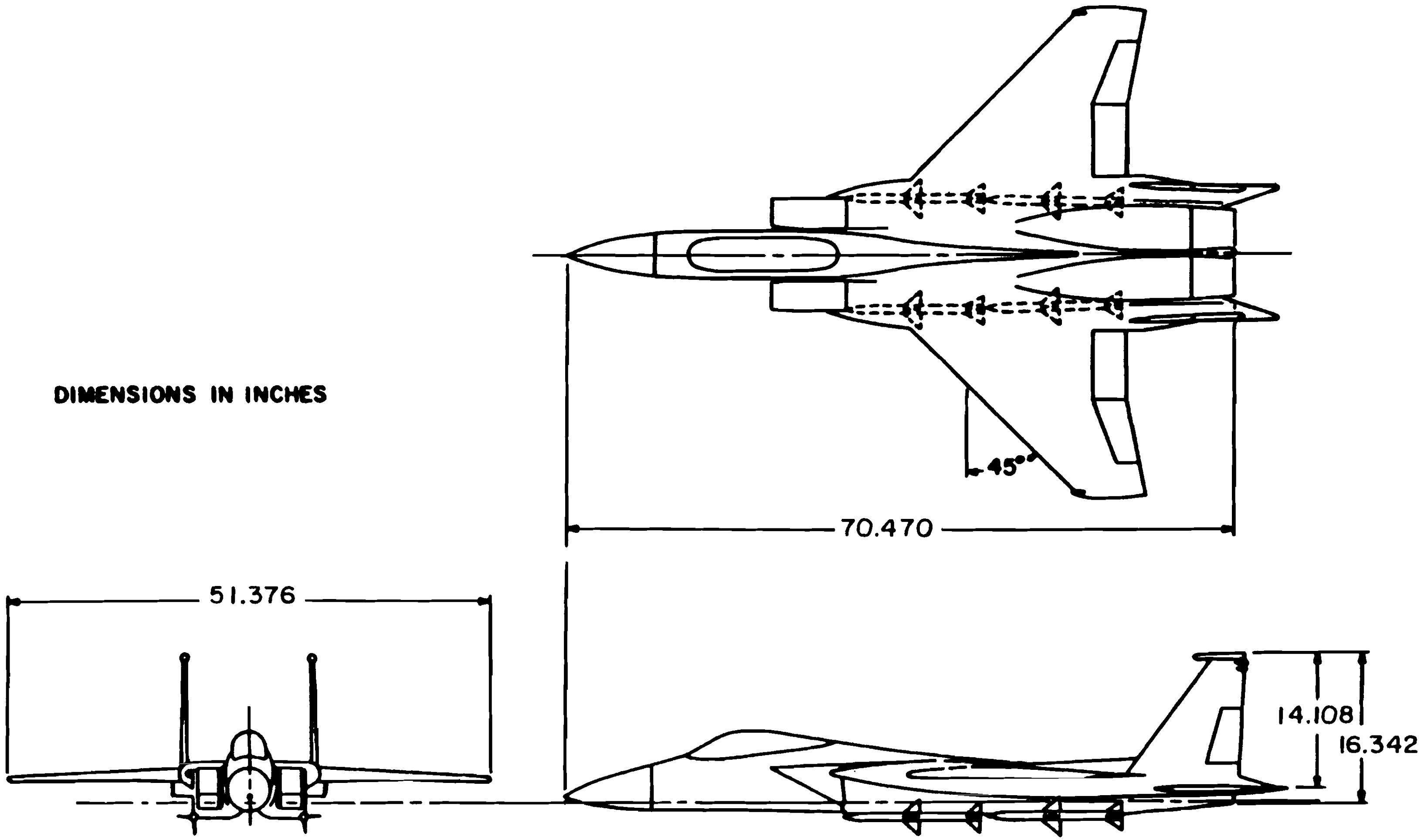


Figure 6. 1/10-Scale F-15 Aircraft Model

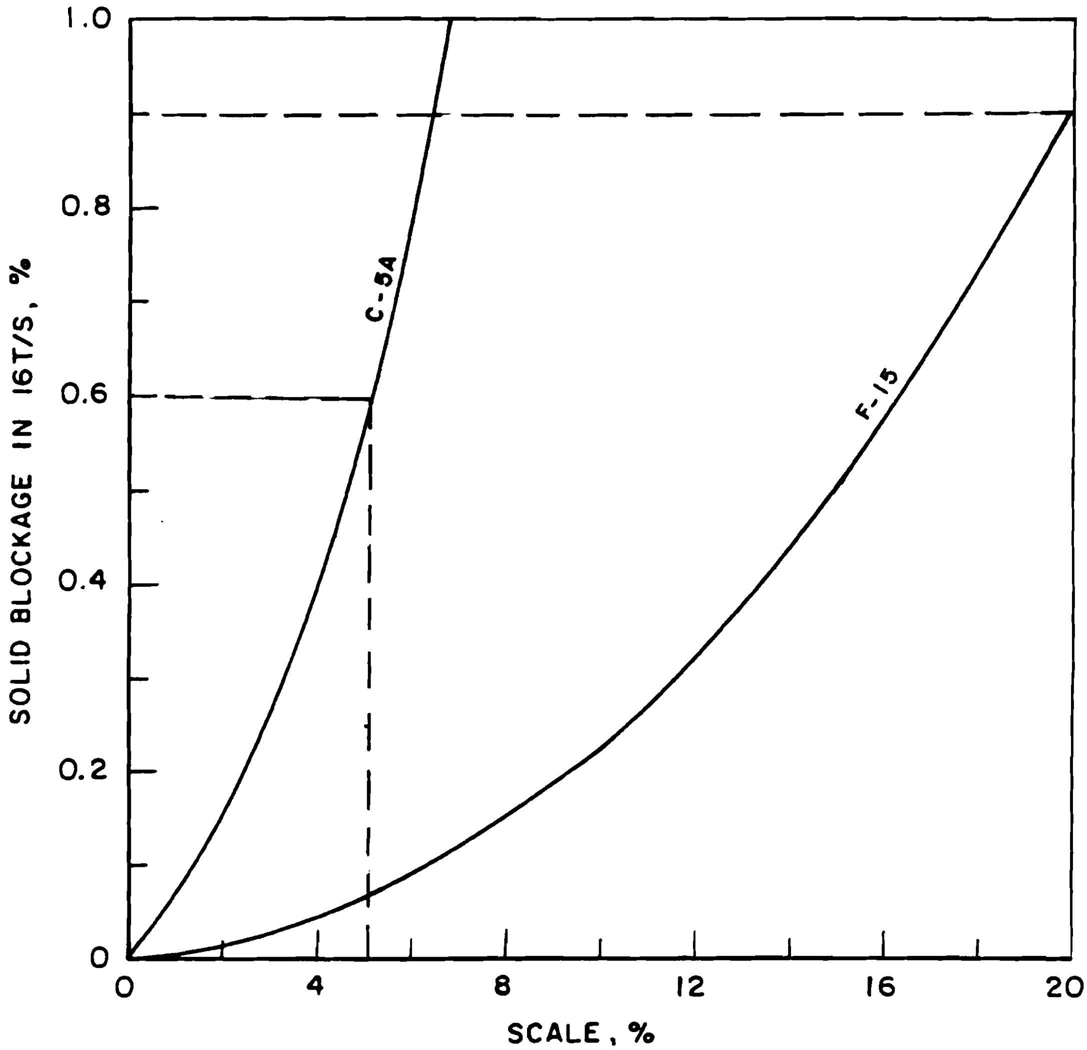


Figure 7. Solid Blockage in 16T/S of the C-5A and F-15 Aircraft at Various Scale Factors

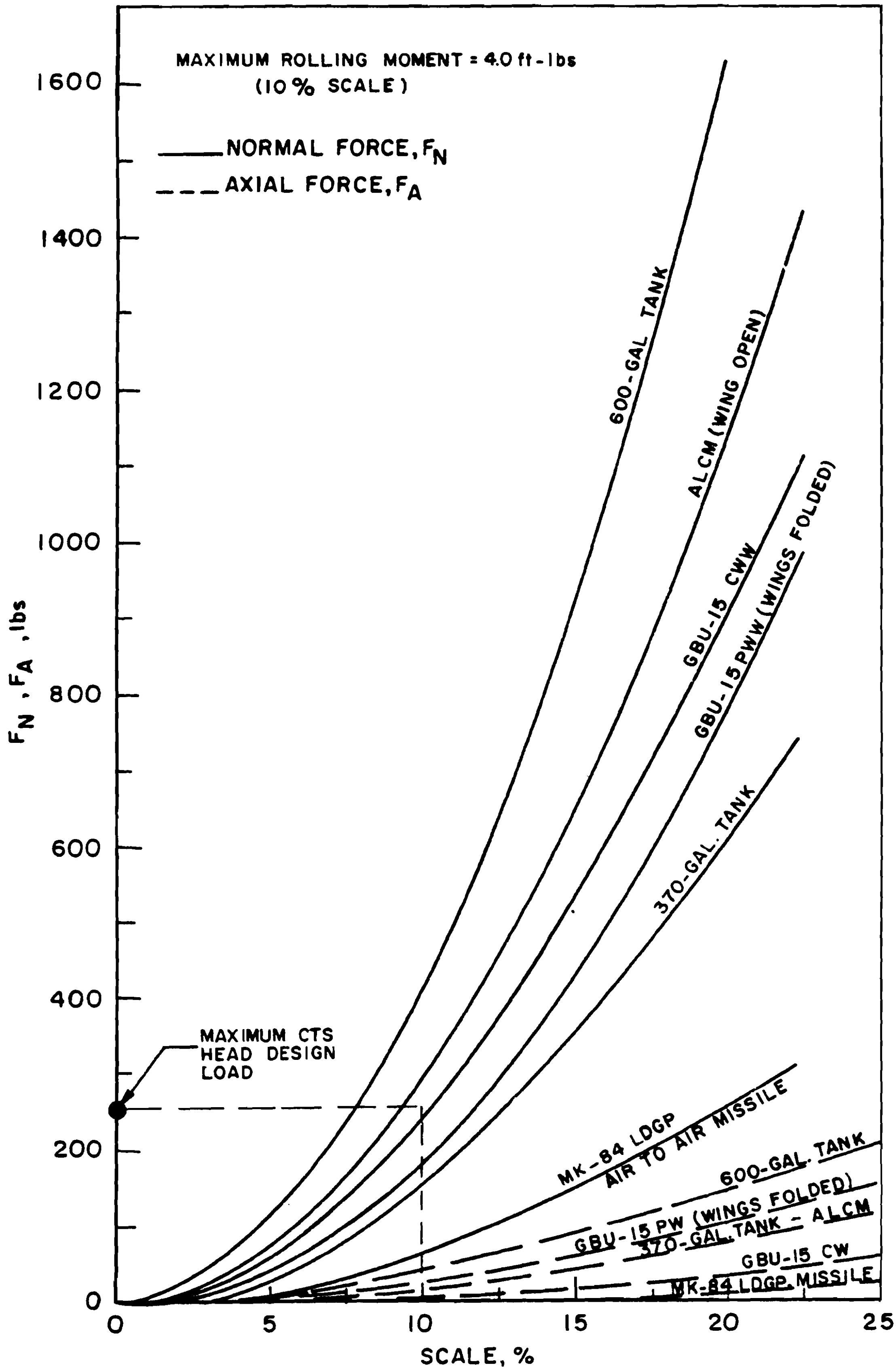


Figure 8. Store Model Loads at Pitch and Yaw Angles of 45°, q = 500 lb/ft^2

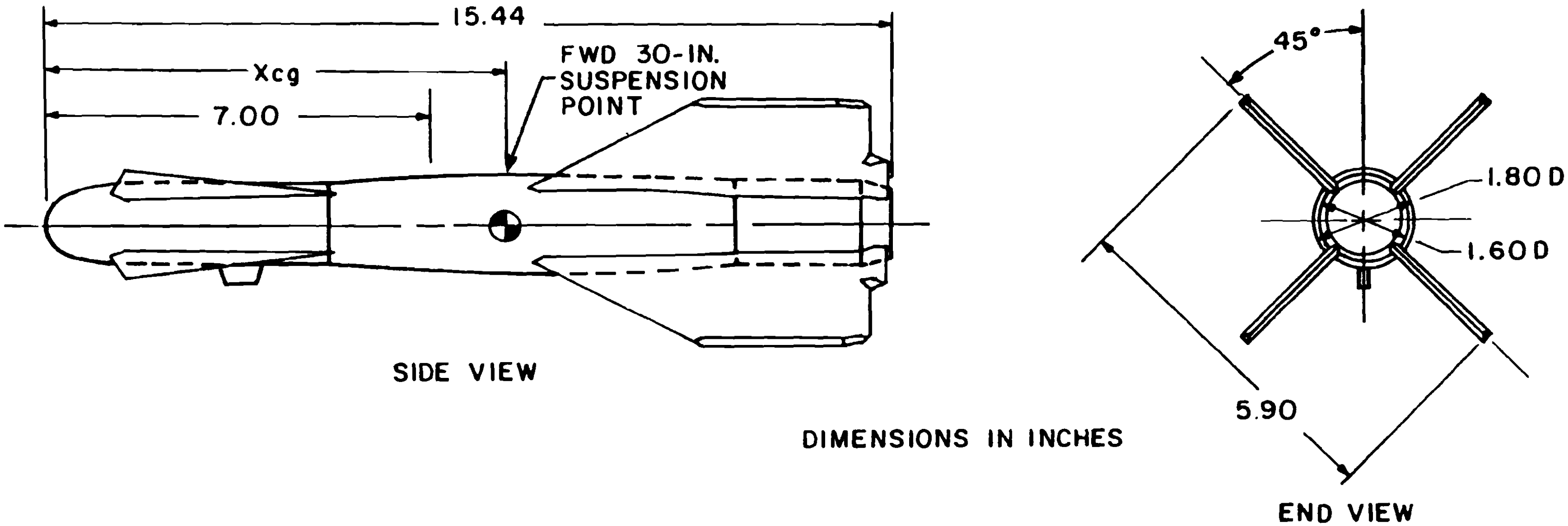


Figure 9. 1/10-Scale Model of the GBU-15 CWW

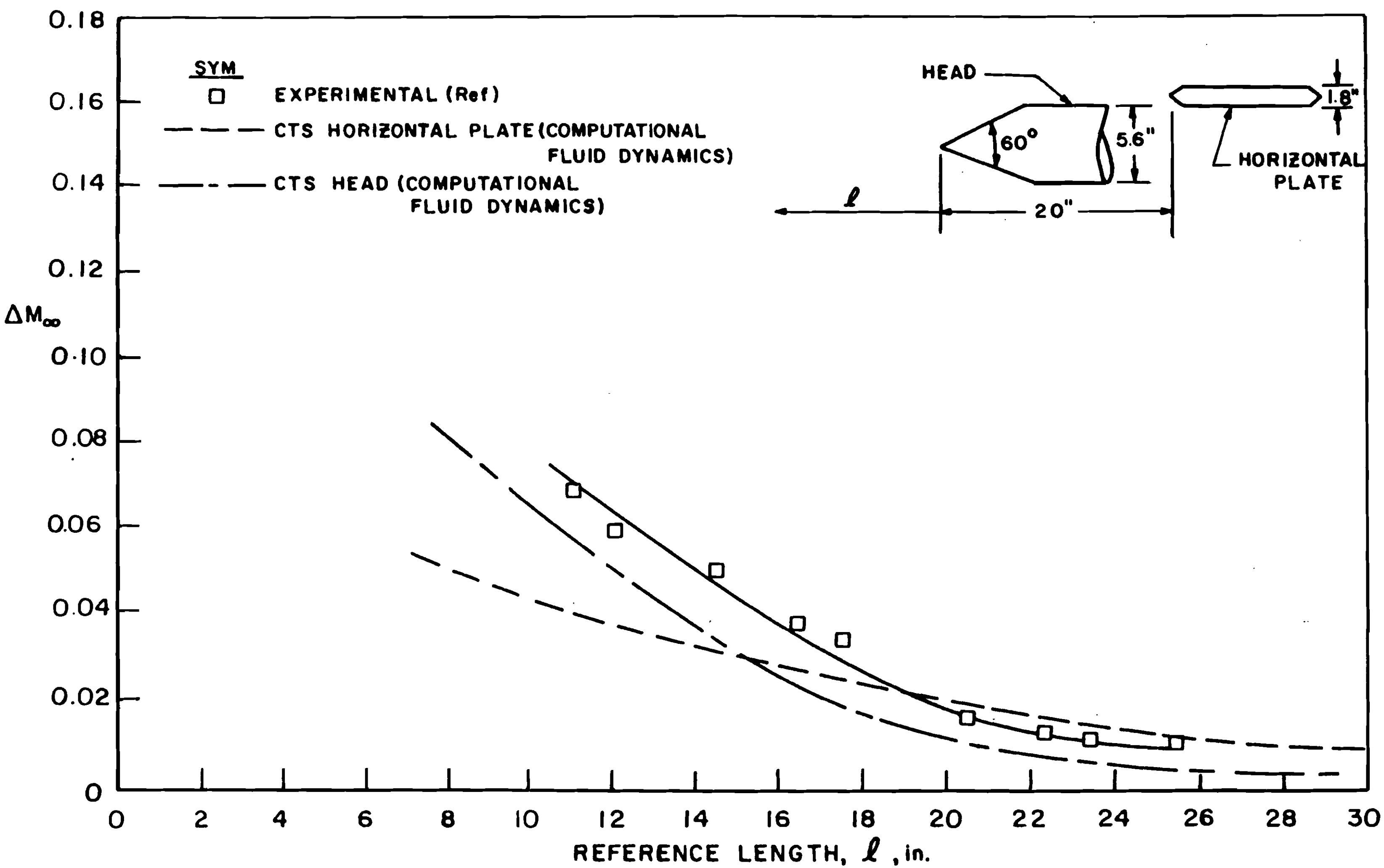


Figure 10. Effect of CTS Rig on Local Mach Number Distribution

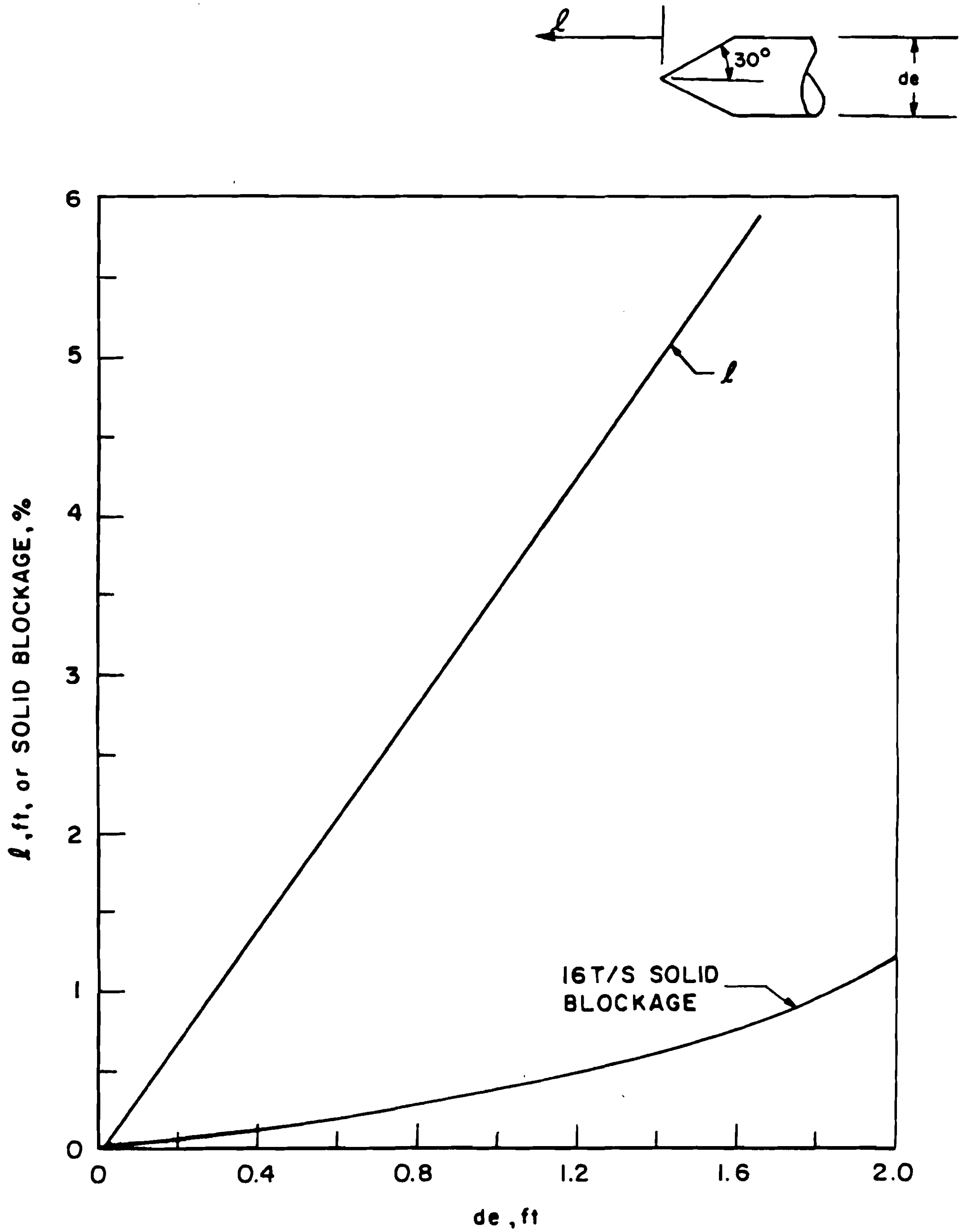
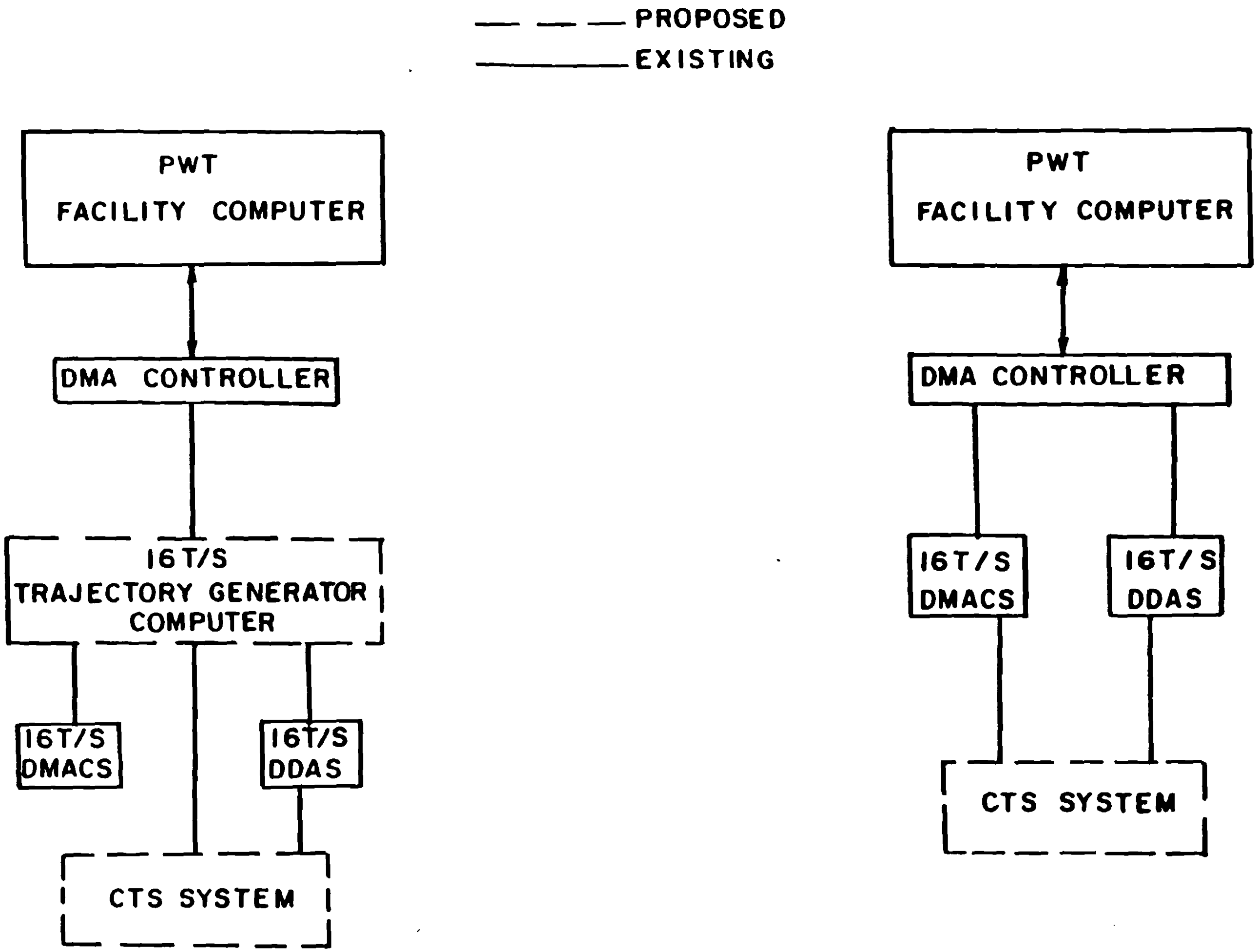


Figure 11. Minimum Sting Length for Minimum Model Aerodynamic Interference



a. 16T/S CTS CONTINUOUS MOTION COMPUTING NETWORK

b. 16T/S CTS MOVE-PAUSE MOTION COMPUTING NETWORK

Figure 12. Proposed 16T/S CTS Control System

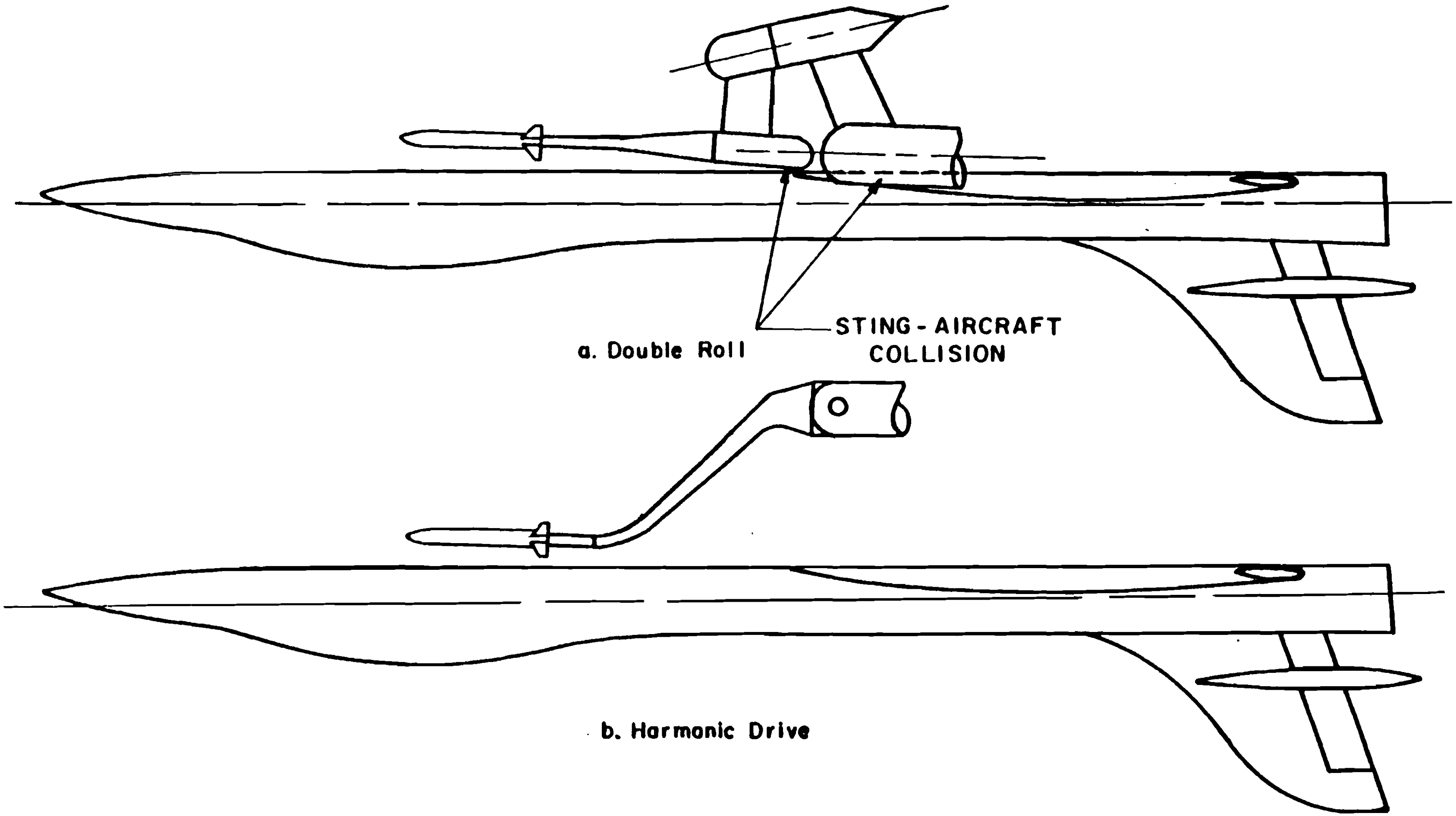


Figure 13. Relative Interference of Double-Roll and Harmonic Drive Heads

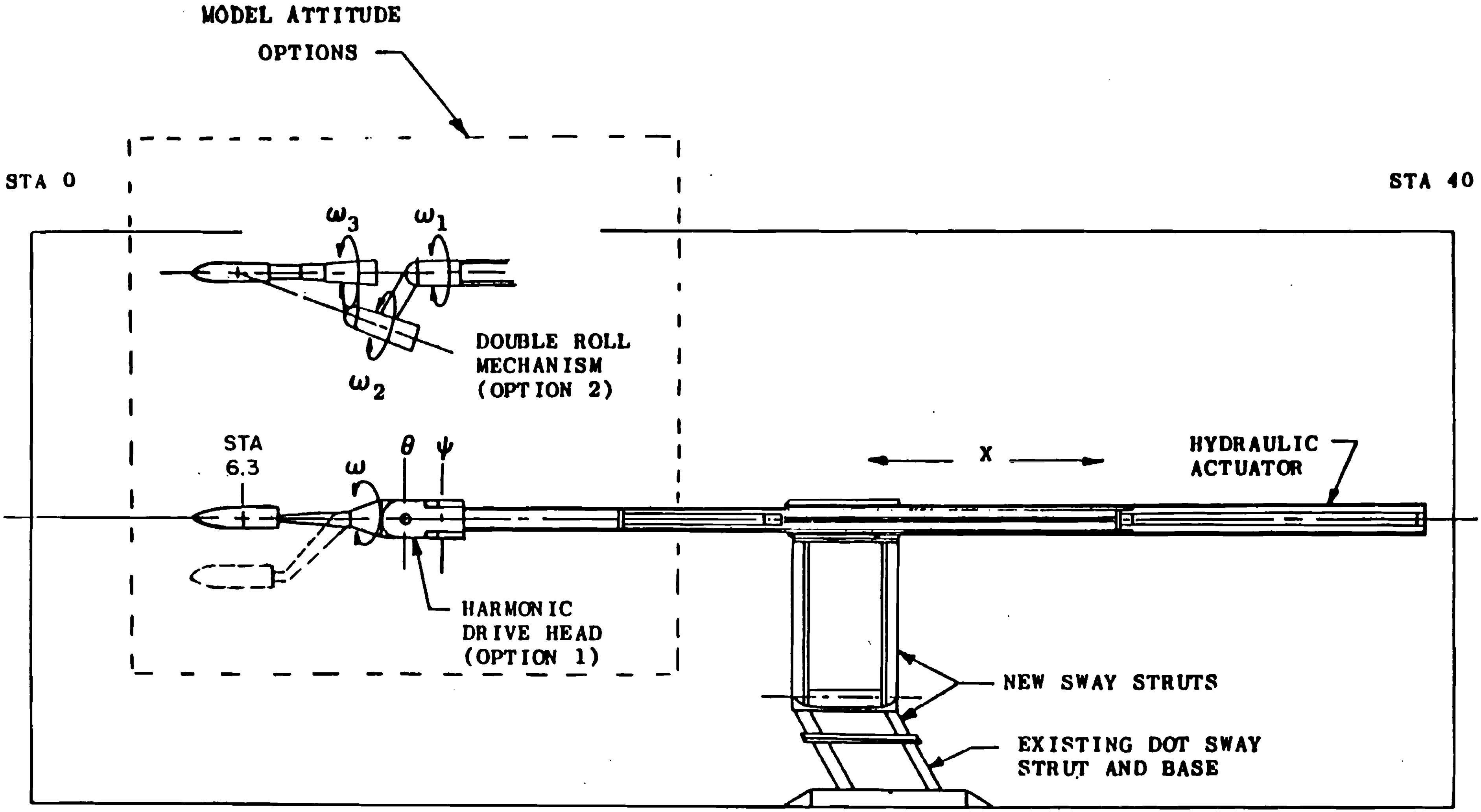


Figure 14. CTS Double Sway Strut with Options 1 and 2 for Model Attitude

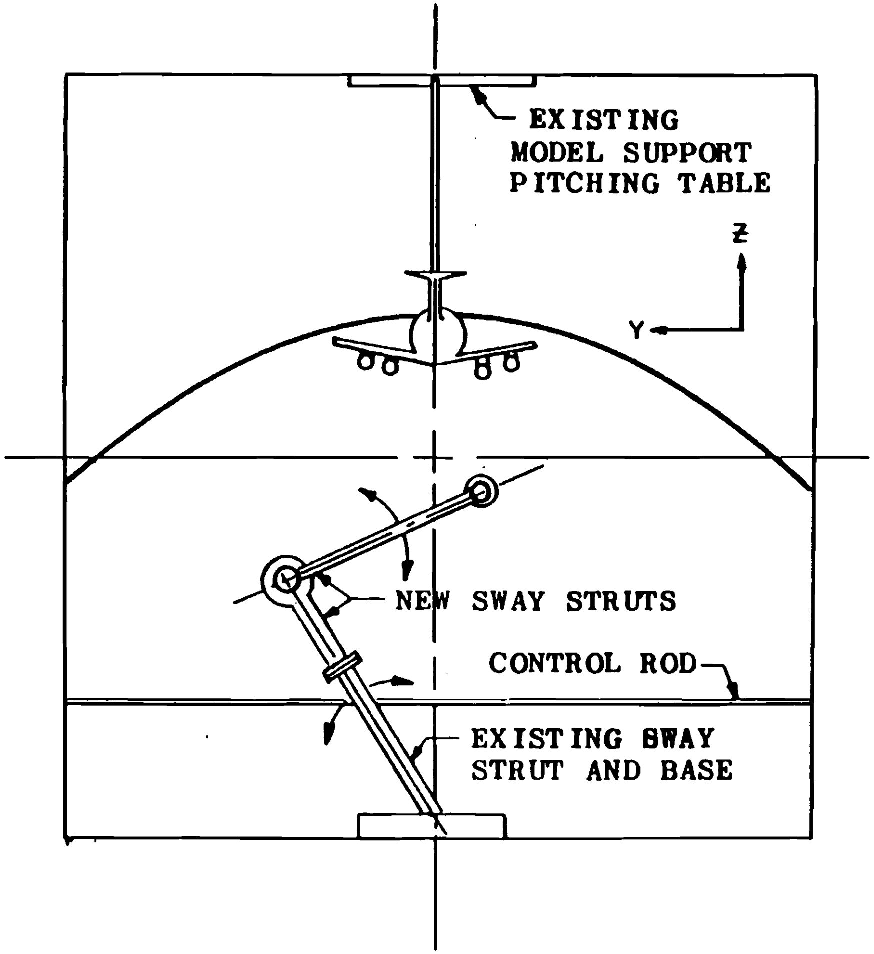


Figure 15. CTS Double Sway Strut Concept

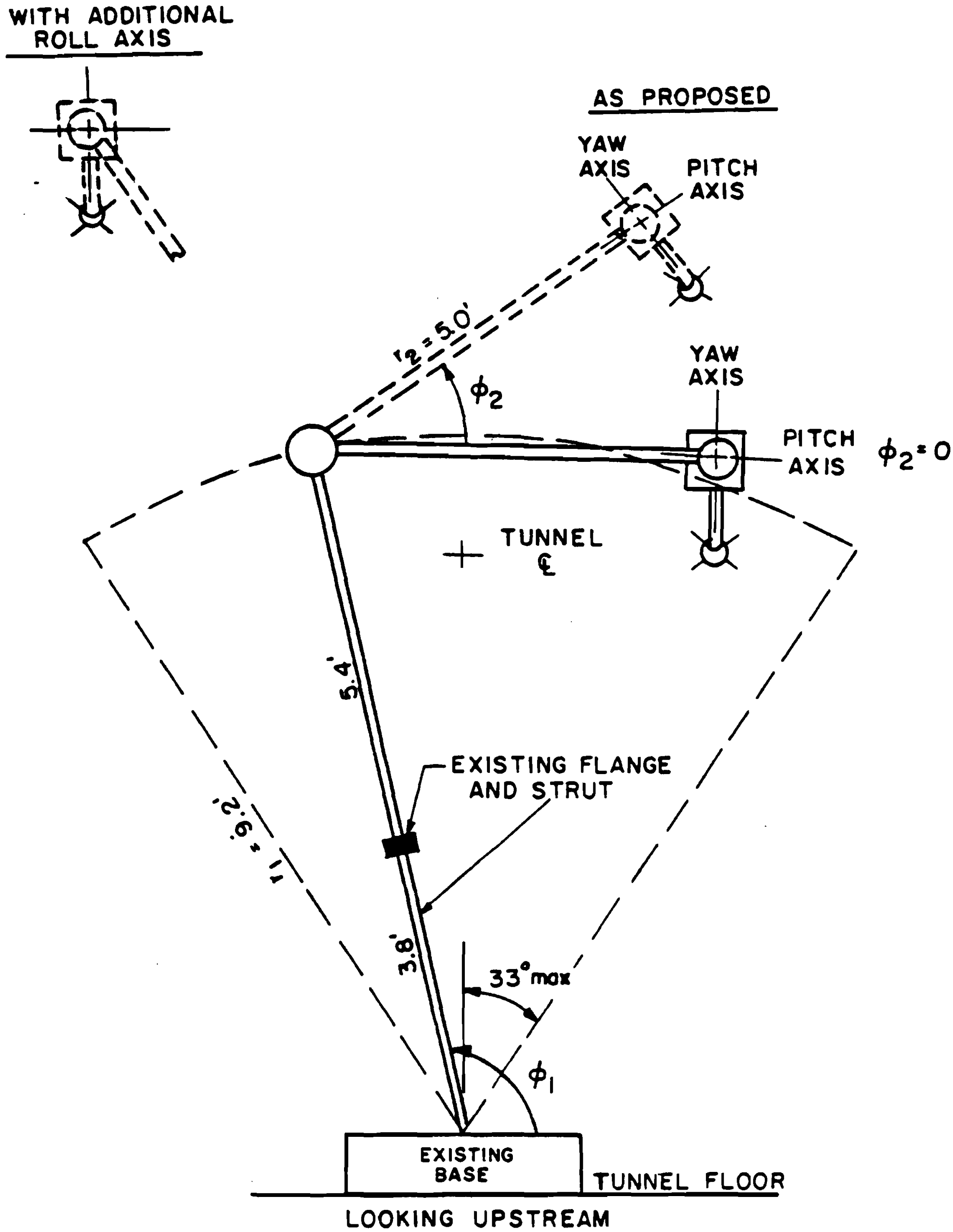


Figure 16. Kinematics of Double Sway Strut with Harmonic Drive Head

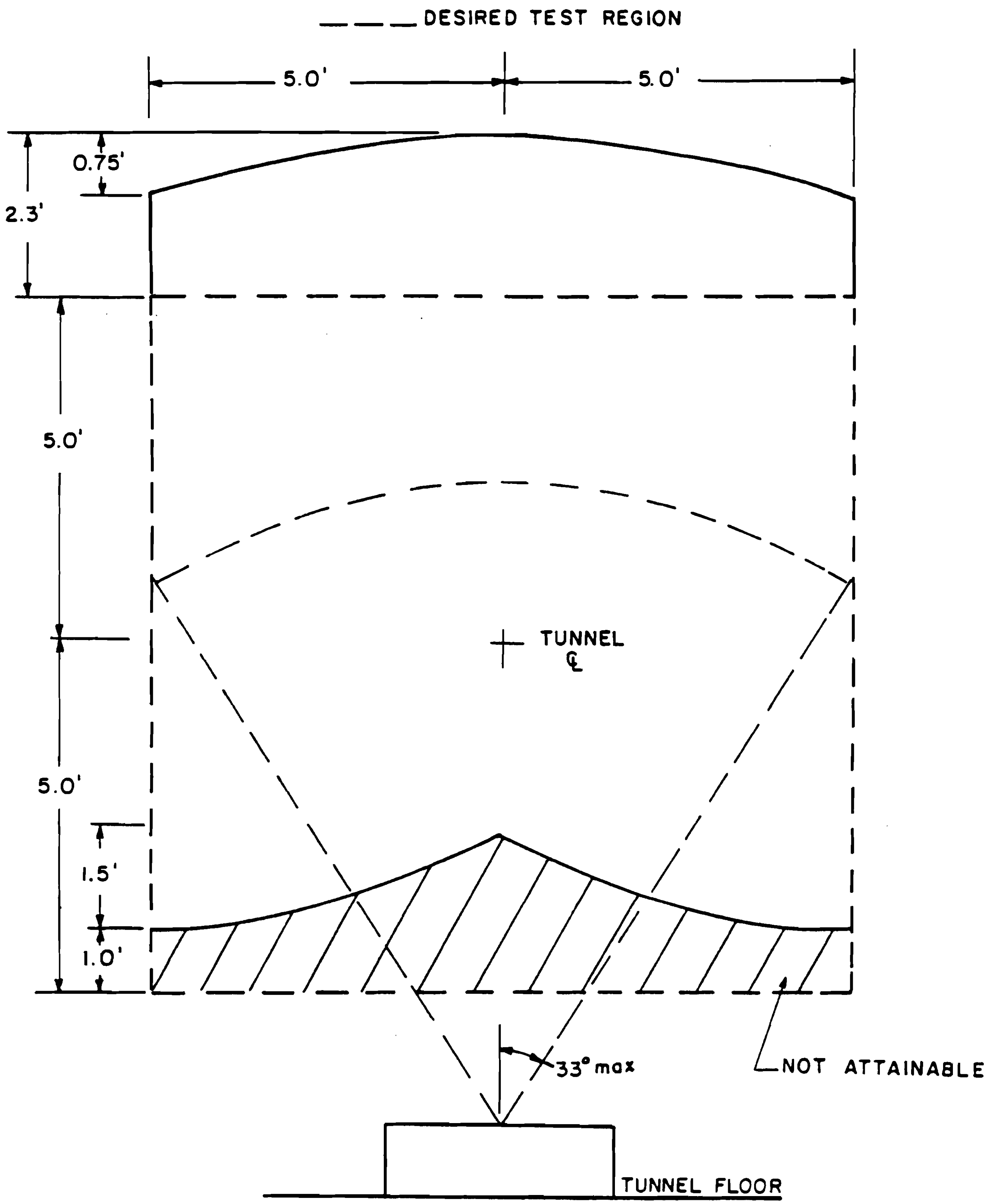


Figure 17. Test Envelope Prescribed by CTS Head on Double Sway Strut

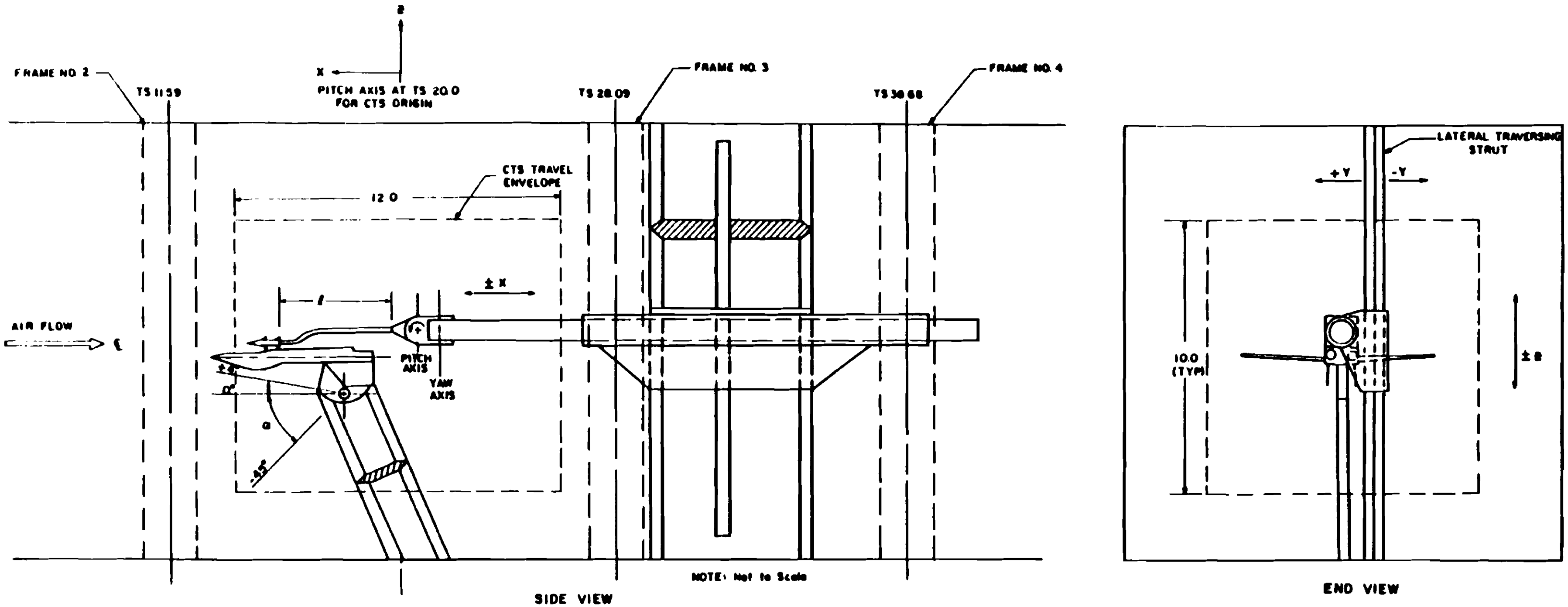


Figure 18. Concept of Full-Span Moving CTS Strut Shown Installed in the 16T Cart with Aircraft

Table 1. 16T/S CTS Concepts Motion Capabilities

COMPONENT	DOUBLE SWAY STRUT			FULL SPAN STRUT		
	TRAVEL LIMITS	POSITIONAL ACCURACY	VELOCITIES	TRAVEL LIMITS	POSITIONAL ACCURACY	VELOCITIES
AXIAL (X)	± 42 in.	± 0.10 in.	Var. 20.0 in./sec (max)	± 72 in.	± 0.10 in.	7.0 in./sec
LATERAL (Y)	± 60 in.	± 0.26 in.	Var. 8.0 in./sec (max)	± 60 in.		2.0 in./sec
VERTICAL (Z)	87.6 to -30 in.	± 0.10 in.	Var. 5.0 in./sec (max)	± 60 in.		2.0 in./sec
PITCH (ν)	± 45 deg	± 0.10 deg	2.5 deg/sec	± 45 deg	± 0.15 deg	2.5 deg/sec
YAW (η)	± 45 deg	± 0.10 deg	2.5 deg/sec	± 45 deg		2.5 deg/sec
ROLL (ω)	± 190 deg	± 1.00 deg	4.5 deg/sec	± 190 deg	± 1.00 deg	10.0 deg/sec

Table 2. Linear Deflections of Support Struts

DOUBLE SWAY STRUT *

STRUT THICKNESS (in.)	STRUT CONFIG ϕ_1	ϕ_2	ΔX (in.) AIR LOAD DEFL. ONLY	ΔX (in.) WEIGHT ONLY	ΔX (in.) POS. CONTROL ACCURACY	ΔY (in.) AIR LOAD DEFL. ONLY	ΔY (in.) WEIGHT ONLY	ΔY (in.) POS. CONTROL ACCURACY	ΔZ (in.) AIR LOAD DEFL. ONLY	ΔZ (in.) WEIGHT ONLY	ΔZ (in.) POS. CONTROL ACCURACY
4	90	40	-0.31	0.14	±0.10	0.57	0.23	±0.26	0.41	-0.85	±0.01
5	↓	↓	-0.19	0.09	↓	0.35	0.14	↓	0.26	-0.54	↓
6	↓	↓	-0.13	0.06	↓	0.25	0.08	↓	0.19	-0.40	↓
4	123	0	-0.08	0	±0.10	-0.18	0.02	±0.15	-0.02	-0.88	±0.10
FULL SPAN STRUT *											
4	—	—	-0.03	0.02	±0.10	0.17	-0.01	±0.10	0.02	-0.11	±0.10
5	—	—	-0.02	0.02	↓	0.13	-0.01	↓	0.02	-0.11	↓
6	—	—	-0.02	0.02	↓	0.11	-0.01	↓	0.02	-0.11	↓

* Values calculated for strut fixed at wall.

Table 3. 16T/S CTS System Procurement Schedule

a. FY '83 Schedule, Velocity Control

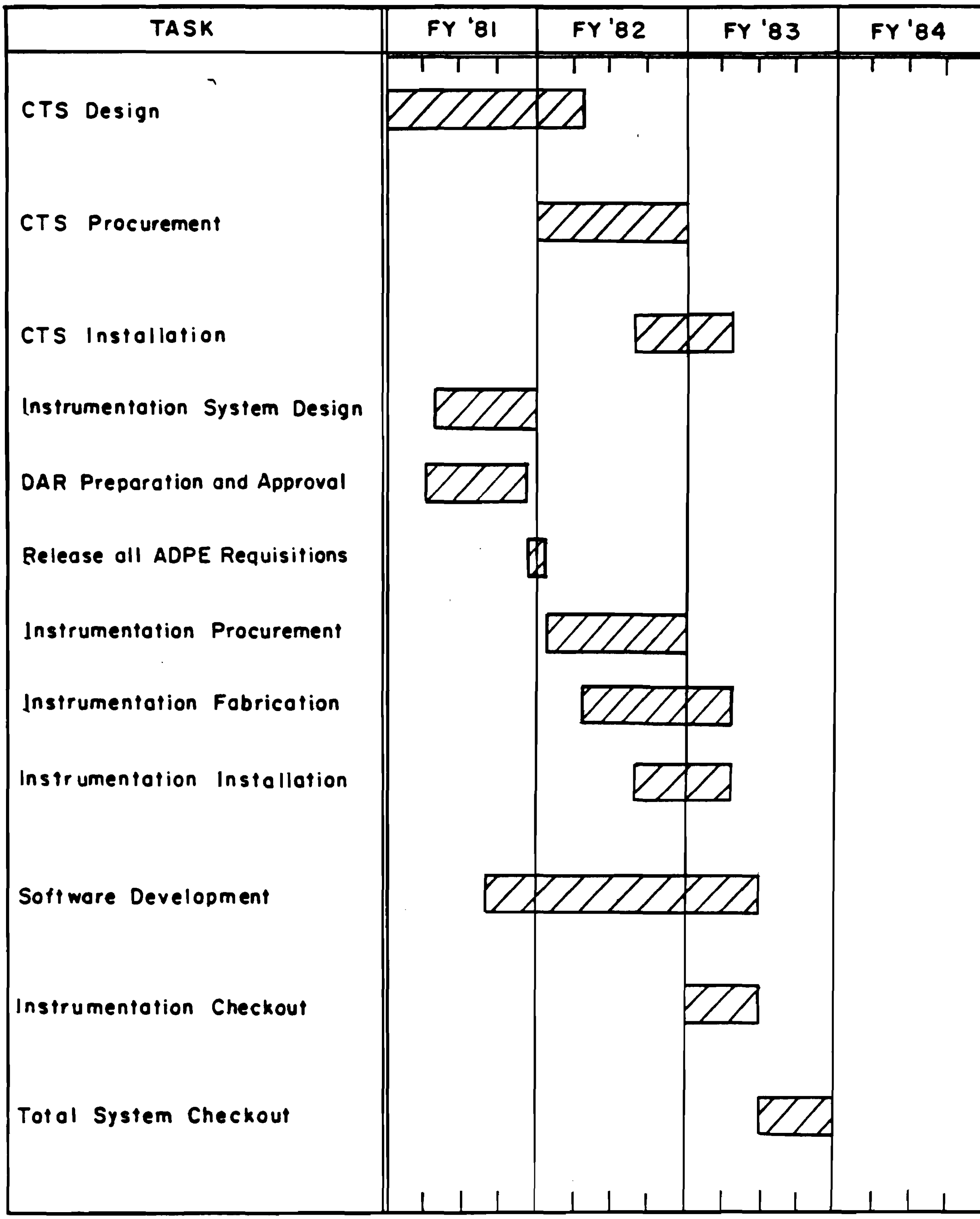


Table 3. Continued

b. FY '82 Schedule, Velocity Control

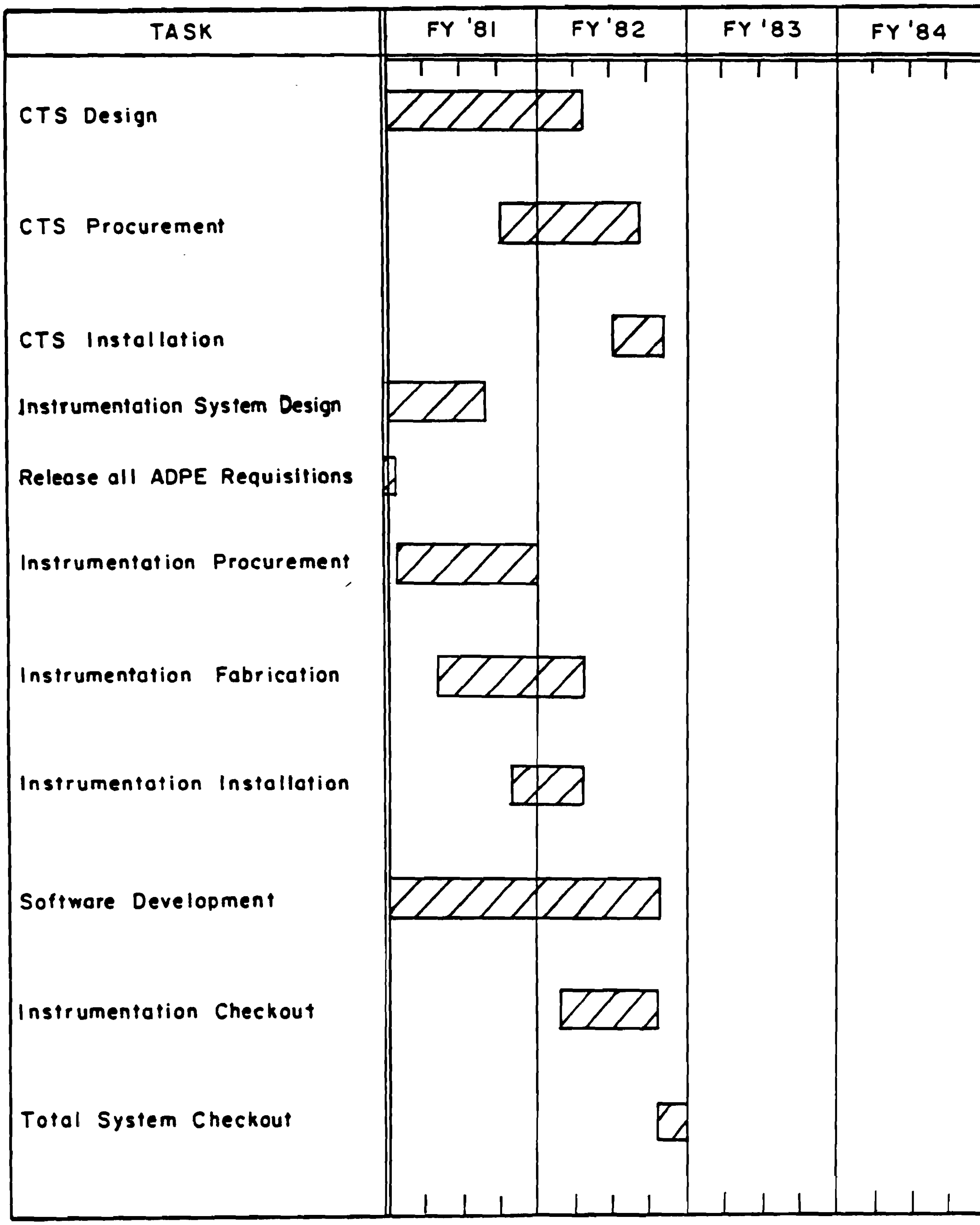
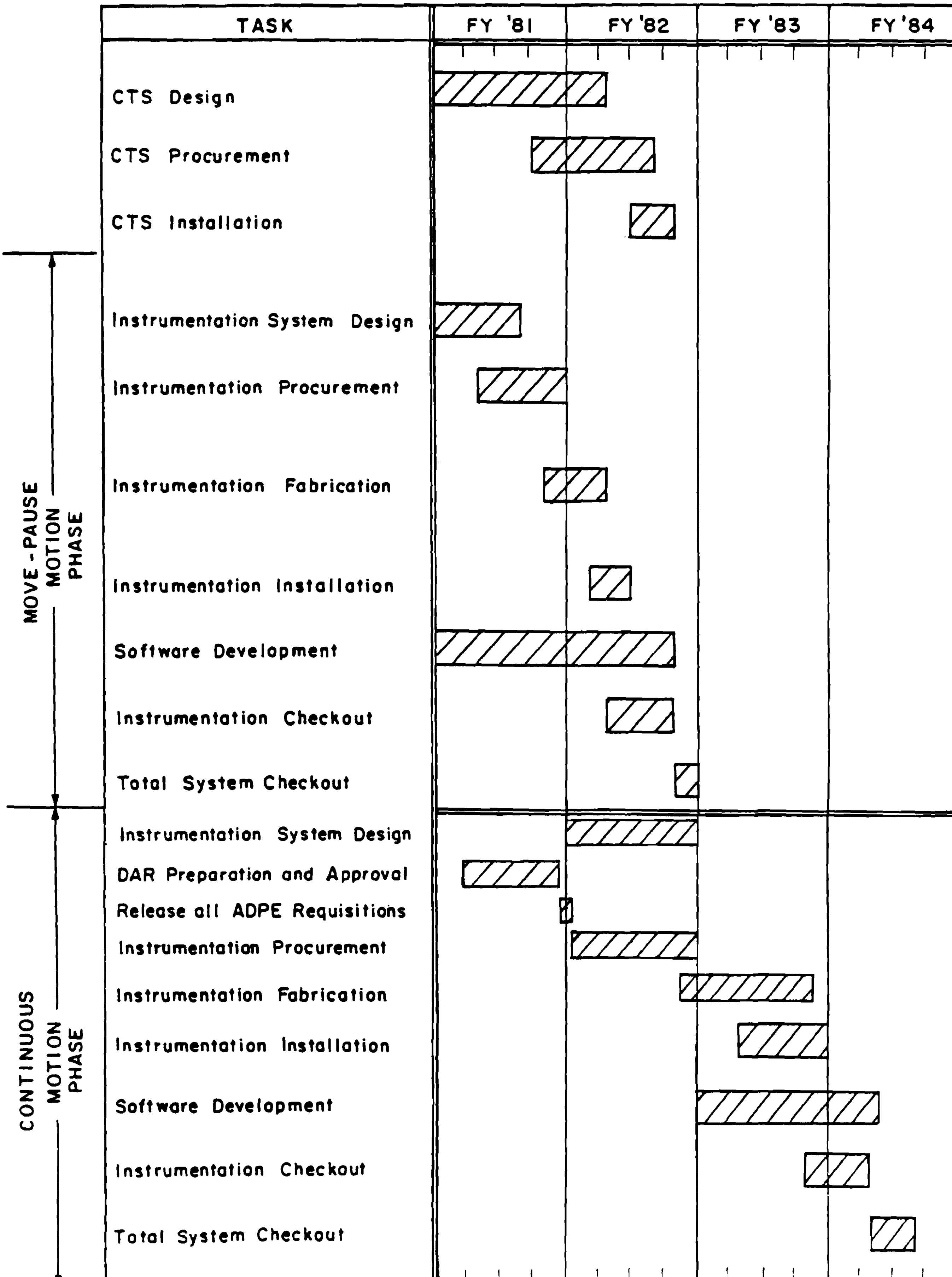


Table 3. Concluded

c. FY '82 Schedule, Position Control



APPENDIX

PRELIMINARY DESIGN CRITERIA

16T/S CAPTIVE TRAJECTORY SUPPORT (CTS) SYSTEM

I. General Concept Guidelines for CTS:

- CTS uses an existing test section cart (1, 4 or 5)
- Installation and removal must be relatively expedient
- Applicable to both 16T and 16S
- Computer network and control system comparable to the 4T CTS--if possible
- Cost effective

II. Operational Environment

- Mach Number 0.2 to 1.5 (16T) and Mach Number 1.5 to 3.0 (16S)
- Dynamic pressure - 500 psf
- Total temperature - 60°F to 160°F

III. Aircraft Support Design Criteria

- 10% Scale model
- Preferably supported (inverted) to pitch table
- Angle of attack - -4 to +45° (-4 to +20° normally)
- Yaw angle ±10 deg
- Strut-type support system for minimum physical interference with the CTS
- Remote angle of attack positioning - 2 deg/sec
- Rotation center of support near aircraft model
- Strut supported laterally to reduce dynamics

IV. CTS Design Criteria

- 10% scale store model

- CTS translational and angular velocities, travel limits and positional accuracy:

	Velocities	Travel Limits	Accuracy
Axial (x)	7.0 in/sec	±72 in.	±0.15 in.
Horizontal (y)	2.0 in/sec	±60 in.	
Vertical (z)	2.0 in/sec	±60 in.	
Pitch (ν)	2.5 deg/sec	±45 deg	±0.15 deg
Yaw (η)	2.5 deg/sec	±45 deg	
Roll (ω)	10 deg/sec	±190	1.00 deg

NOTE: CTS Pitch center origin at TS=20 (Cart 1), TS=10 (Cart 4 or 5)

- Pitch axis forward of yaw axis

- CTS Roll axis and balance axis offset angle -0 to -30°

- Estimated usage of the 16T/S CTS - 100 hrs/yr (AOH)

V. Instrumentation Requirements

- Sting, CTS, and aircraft electrically isolated to provide system safety when physical contact occurs

- The CTS would consist of a closed-loop feedback control system

- The control system would use hydraulic actuators or DC motors where applicable

- Final CTS system would use continuous motion technique via velocity control

- A stand-alone trajectory generator computer for permanently servicing tunnels 16T and 16S and test cart in MI Bldg.

- The microprocessor-based controller in a portable system for check-out during model build-up in MI Bldg. would be interfaced with Trajectory Generator Computer

- Optical sensors, and signal conditioning equipment (same as 4T) for store model alignment